Spur Development of 'Delicious' Apple as Influenced by Position, Wood Age, Strain, and Pruning

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Abstract. The role of spur leaves in bud and fruit development on two spur-type 'Delicious' apple strains (*Malus domestica* Borkh.) and factors affecting spur development were studied. Reducing spur leaf area on vegetative spurs in August reduced the number of spurs that flowered the following year but did not affect flower size. On spurs that did flower, leaf area reduction the previous year did not influence leaf number or area, but the bourse shoot leaf area was reduced. Spur bud diameter, leaf area, size, specific leaf weight (SLW), and leaf dry weight were larger on 2-year-old vegetative spurs than on 1- or 3-year-old spurs. Within each age section of a limb, spur leaf number, area, size, SLW, and bud diameter decreased from the apical to basal positions on the limb. Flower number did not vary within a limb section, but fruit set was lower on the most apical and basal spurs compared to midshoot spurs. Fruit size was largest at the apical end of each limb section and was smallest at basal positions. These relationships were not affected by strain, tree age, or orchard location. Summer pruning at 30 days after bloom tended to increase leaf number, area, size, and spur length compared to unpruned trees or pruning later in the season but did not influence spur bud diameter.

Apple spur leaves are important to potential fruit production and quality. They are the first leaves on the tree after bud break and comprise the majority of the tree canopy un-

til after bloom (Ferree and Palmer, 1982; Forshey et al., 1987). and the primary leaves on a fruiting spur provide the majority of new carbohydrates necessary for early fruit growth (Hansen, 1971). Reducing leaf area or shading spur leaves before or during bloom reduces fruit set and size (Ferree and Palmer, 1982; Rom and Ferree, 1984c). The leaf area on spurs during bloom correlates with long-term productivity of several cultivars (Rom and Ferree, 1984a).

Spur leaf area can vary 35% to 50% among spurs on a tree and between different trees, with the leaf area of the largest spur being as much four times that of the smallest spur on a tree (Rom and Ferree, 1984a, 1984b). These differences may be a source of vari-

ation in fruit set, size, and quality. However, sources of variation in spur leaf area and spur development have not been well-documented.

Reducing vegetative-spur leaf area before flowering has resulted in fewer spurs forming flower buds and in poor set the following spring (Harley et al., 1942). Bud diameter of 'Delicious' varies with position on the limb (Walsh, 1979) and spur bud diameter positively relates to fruit set (Blasberg, 1943). Fruit size and quality vary with the spur age (Robinson et al., 1983; Rom and Ferree, 1984a) and the light environment surrounding the apple (Barritt et al., 1987; Robinson et al., 1983; Rom and Ferree, 1984c). Although these studies reported factors that influence fruit set, size, quality, and spur quality, they did not investigate carryover effects of spur quality from one season to the next or the influence of spur position, spur age, or cultivar strain. Thus, studies were conducted to evaluate how variation in vegetative-spur leaf area affects fruiting-spur development and to determine sources of naturally occurring variation in spur development within trees.

To study the importance of vegetative-spur leaf area in spur development the following season, leaf area of vegetative spurs (non-flowering or fruiting) was adjusted to the following levels: 1) no leaf removal, 2) 50% leaf area removed, and 3) 80% + leaf area removed. The 50% leaf area was created by cutting all leaves in half. The 80% + treatment was produced by removing all but one leaf, typically the small terminal leaf, which, in turn, was cut in half. The half leaf that remained on the 80% treatment prevented buds from opening, blooming, or resuming vegetative growth immediately after treatment. Treatments were applied to 14-year-old 'Starkrimson Delicious'/MM.106 trees in the Washington State Univ. (WSU) Horticulture Orchard (Pullman, Wash.), on 1 Aug. 1985 and on 7-year-old 'Oregon Spur Delicious'/M.7 trees in the WSU-Tree Fruit Research Center (TFRC), Columbia View

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Orchard (near Wenatchee, Wash.), on 9 Aug. 1985. For trees in the Pullman orchard, seven multiple-spur complexes (with a minimum of five spurs per complex) per treatment on each of 10 replicate trees were used. In the Wenatchee orchard, 10 spurs randomly selected on three to four limbs were selected on 16 replicate trees. In both locations, at least 35 sample spurs per treatment per replicate were studied.

The number and percentage of spurs flowering in the spring after treatment were reduced in proportion to the leaf area removed (data not presented). However, the king bloom receptacle diameter on flowering spurs was

similar at full bloom (Pullman) and there was no difference in the number of flowers per spur or fruit set per cluster (Wenatchee). A frost after bloom resulted in discontinuation of the Pullman trial.

Spurs that had been treated the previous season in Wenatchee were sampled 25 July 1986. Two types of spurs were sampled: 1) fruiting spurs that had set fruit, and 2) vegetative spurs (spurs that were treated but did not flower). Fruiting-spur leaf area per spur, specific leaf weight (SLW), average leaf size, and leaf dry weight per spur did not differ with treatments. However, the bourse shoot leaf area of fruiting spurs was 21% and 46%

less than controls for the 50% and 80%+ treatments, respectively. The bourse shoot is important for continued growth of fruits after primary spur leaf development is complete (Abbott, 1960). On spurs that remained vegetative, leaf area and leaf dry weight per spur were increased by leaf removal treatments (data not presented).

Thus, there appeared to be a carryover effect of the leaf area on vegetative spurs for flower and spur development the following year. The primary effect was on flowering. Removal of vegetative-spur leaf area reduced flowering and, thus, was similar to the observations of Harley et al. (1942). The effects on fruiting-spur development were less obvious. Only spurs that set fruit were sampled, thus possibly excluding spurs with lesser leaf area that did not set fruit. Bourse shoot growth on fruiting spurs was reduced by removing vegetative-spur leaves the previous season during bud development. It is unclear why spurs that remained vegetative after leaf removal had increased leaf area.

A second study was established on 8 Aug. 1985 at the WSU-TFRC Columbia View Orchard to evaluate variation in spurs within the canopy. Uniform lower scaffold limbs were selected on each of ten 'I-year-old trees of 'Redspur Delicious' and 'Oregon Spur Delicious' on M.7a rootstocks. Five equally distributed vegetative spurs were sampled from 1-, 2-, and 3-year-old limb sections. On similar limbs on the same trees, a second set of spurs was labelled to identify the spurs the next season. The spurs from each limb section were also identified by position within the section from apical to basal positions. The experiment was designed as a randomized complete block and analyzed as a split-split-split plot for strain, spur position, and limb section. Data were analyzed with the SAS program package (Statistical Analysis Systems Institute, Inc., Gary, N.C.) using least significant difference to separate means.

Vegetative-spur leaf number and spur length increased from the youngest limb section to the oldest section (Table 1). However, bud diameter, spur leaf area, leaf size, SLW, and leaf dry weight per spur were largest on the 2-year-old limb section. Leaf number and leaf area were most variable on the 1-year-old limb section (cv = 38.2, 53.0, respectively) but variability decreased on older limb sections. Bud diameter was least variable on the 1-year-old limb section and greatest on the 3-year-old limb section (cv = 12.4, 15.4, respectively).

Spur leaf number, area, size, SLW, spur length, and bud diameter decreased from the apical to the basal positions on the limb (Table 1). Walsh (1979) observed that spur bud dry weight decreased from apical to basal sections on three spur-type strains of 'Delicious'. He concluded that apical buds were more productive. Apical buds may be more productive due to increased leaf area per spur or increased SLW, which relates to the photosynthetic efficiency of the leaves (Barden, 1977). The total photosynthetic capacity of the spur can then be estimated as the SLW $\times$ area, which is equivalent to the total leaf

Table 1. The influence of limb section age, position within a section, and cultivar strain on vegetative spurs of 'Delicious' apple¹.

Variable ²	Vegetative-spur leaves				Leaf size (cm ²)	Spur length (mm)	Bud diam (mm)
	Leaf no.	Area/spur (cm ²)	Dry wt/spur (g)	SLW (mg/cm ²)			
Limb section age							
1-year-old	8.6	116	1.2	10.0	13.2	16.8	4.8
2-year-old	10.3	161	1.7	10.4	15.6	24.9	4.9
3-year-old	10.8	149	1.5	9.6	13.7	36.4	4.7
Position within a limb section							
1-apical	10.4	158	1.7	10.4	15.0	28.6	5.0
2	10.2	151	1.6	10.2	14.7	27.6	4.9
3-mid	10.1	143	1.5	10.0	14.1	25.3	4.8
4	8.8	122	1.2	9.6	13.7	21.1	4.7
5-basal	9.3	125	1.2	9.6	13.3	21.0	4.7
Strain							
Oregon Spur	9.9	154	1.6	9.8	15.5	26.9	5.0
Redspur	9.8	127	1.3	10.0	12.7	24.6	4.6
LSD values (<i>P</i> = 0.05)							
Section age	0.5	11.0	0.2	0.3	0.8	1.9	0.1
Position	0.7	14.5	0.2	0.4	0.9	2.9	0.2
Strain	NS	10.8	0.1	0.4	0.9	1.7	0.2

¹All measurements made in Sept. 1985.

²Means for limb age are pooled data from spur position and strains of 10 replications; means for spur position are pooled data from limb sections of 10 replications; means for strains are pooled data from limb section and spur position of 10 replicate trees. NS = nonsignificant.

Table 2. The influence of limb section age, position within a limb section, and strain on fruiting spur development, bloom, fruit set, and fruit size on two swains of 'Delicious' apple¹.

Variable	Fruiting-spur leaves				Flowers/spur (no.)	Fruit (no.)	Fruit set (%)	Fruit wt (g)
	No.	Area/spur (cm ²)	Dry wt/spur (g)	SLW (mg/cm ²)				
Limb section								
2-year-old	15.2	220	2.1	9.1	4.8	0.7	15	202
3-year-old	13.4	164	1.5	8.5	5.2	0.6	10	206
4-year-old	19.4	332	2.9	8.2	4.9	0.4	8	174
Position within a limb section								
1-apical	20.2	341	3.3	9.0	4.7	0.5	10	230
2	15.1	207	1.9	8.9	5.1	0.6	11	199
3-mid	15.5	220	2.0	8.5	5.3	0.6	11	202
4	14.8	222	1.9	8.6	4.8	0.6	13	214
5-basal	14.2	194	1.7	8.2	4.8	0.5	10	183
Strain								
Oregon Spur	15.8	249	2.2	8.4	5.1	0.5	11	197
Redspur	16.2	227	2.1	8.9	4.8	0.6	12	197
LSD values (<i>P</i> = 0.05)								
Section	3.1	81	0.8	0.3	NS	0.1	2	17
Position	1.2	35	0.5	0.5	NS	NS	3	33
Strain	NS	22	0.1	0.4	NS	NS	NS	NS

¹Flowers per spur counted at full bloom (28 Apr.). Fruit no. per spur and fruit set counted on 27 July. Spurs sampled in Sept. 1986. Means for limb age are pooled data from spur position and strains of 10 replications; means for spur position are pooled data from limb sections and strains of 10 replications; means for strains are pooled data from limb section and spur position of 10 replicate trees. NS = nonsignificant.

Table 3. The influence of summer pruning at two dates on vegetative-spur development of 'Oregon Spur Delicious' apples¹.

Summer pruning treatment ²	Spur leaf no.	Spur length (mm)	Bud diam (mm)	Spur leaves			Leaf size (cm ²)
				Area/spur (cm ²)	Dry wt/spur (g)	SLW (mg/cm ²)	
None	10.0	25.6	4.8	133	1.39	9.9	13.2
30 DAFB	10.1	26.0	4.9	151	1.58	10.3	14.8
70 DAFB	9.4	23.5	4.8	138	1.38	9.8	14.6
LSD values (<i>P</i> = 0.05)	0.4	2.3	NS	15	0.10	NS	1.4

¹Means are pooled from 15 spurs per tree with 10 replicate trees of each treatment. NS = nonsignificant.

²DAFB = days after full bloom.

dry weight per spur. In this study, leaf dry weight per spur was 39% greater on apical than on basal spurs.

Spur development differed significantly between the cultivar strains (Table 1). 'Oregon Spur' trees had longer spurs, more leaf area, larger leaf size, and larger buds. Spur quality characteristics have been correlated with the long-term productivity of cultivars (Rom and Ferree, 1981a). However, insufficient yield records were available to make correlations in the current study. There were no interactions between limb age, position on an individual limb section, and cultivar strain for any spur quality characteristic measured. From these data and a previous report showing similar trends for other 'Delicious' strains (Walsh, 1979), we suggest that these phenomena are similar for many spur strains of 'Delicious'.

Spurs that had been tagged the previous fall were counted for individual flowers per spur at full bloom on 28 Apr. and resulting fruit were counted 27 June. Fruiting spurs and fruits were harvested in Sept. 1986.

Fruiting spurs of the oldest limb section had more leaves and greater leaf area but lower SLW than spurs on the youngest section (Table 2). Limb section age did not significantly influence the number of flowers per spur. However, fruit set was less on the 3- and 4-year-old limb sections than on the 2-year-old limb section.

Fruiting spurs at the apical end of a limb section had the most leaves, largest leaf area, greatest dry weight per spur, and highest SLW (Table 2). The position of the spur within the limb section did not influence the number of flowers per spur. Spurs in either the most apical or most basal position had lower fruit set than those in the midshoot positions.

Flower number per spur was significantly correlated (*P* < 0.001) to bud diameter measured the previous fall (*r* = 0.41, limb sections and cultivars pooled). The correlation was strongest for the 3-year-old limb section (*r* = 0.53) and poorest for the 2-year-old section (*r* = 0.36). 'Oregon Spur' had a higher correlation between bud diameter and flower number per spur than 'Redspur' (*r* = 0.45 and 0.38, respectively). However, bud diameter was not significantly correlated to fruit set in our study, contrary to results reported by Blasberg (1943). Fruit had been chemically thinned with 4,6-dinitro-orthocresol (Elgetol) at ≈85% full bloom and with carbaryl at 15 days after bloom. The thinning treatments would have removed flowers that

bloomed late or fruitlets that were less competitive, possibly masking bud diameter to fruit-set relationships.

Fruits on the 2- or 3-year-old limb sections were larger than those on the 4-year-old section (Table 7). Fruits at basal positions in a limb section were significantly smaller than fruit at apical positions, regardless of the limb section age. There was no interaction between limb section age and position on a section at which fruit developed. Fruits were the most uniform, but significantly smaller, on the 4-year-old section. Although limbs were originally selected to avoid limitations in light, light may have been limiting on more interior or lower, older limb sections. The combined effects of light and spur age have been shown to affect fruit size (Robinson et al., 1983).

Both strains of 'Delicious' had a similar number of fruiting-spur leaves but 'Oregon Spur' had more spur leaf area and dry weight per spur while 'Redspur' had greater SLW (Table 2). Strain did not influence the number of flowers per cluster, fruit set, or average fruit weight. There was no interaction between cultivar strain and either spur age or spur position for any variable measured.

Similar data were also collected from two additional studies at two different sites with trees 5 or 7 years old. The trends of spur age, spur position, and cultivar were similar throughout all studies (data not presented). Therefore, it is our conclusion that these observations represented a developmental phenomenon.

Relationships of spur characteristics and fruit size have been previously reported (Barritt et al., 1987). Both spur development traits and fruit characteristics were highly related to the light environment in which they developed. In the studies reported here, we did not observe such a close correlation between spur traits and fruit when grown in full light. Fruit weight was significantly negatively correlated to spur age (*r* = -0.20) but not correlated to spur leaf area and leaf dry weight. Although there was large spur-to-spur variation for leaf area (CV = 120%) and other related variables, there was very limited variation in fruit weight (CV = 19%). These data suggest that even though the spur may have some carryover effect in development potential from the previous season, fruit development may be largely controlled by factors during the current season. In particular, leaves other than the spur leaves and the direct light environment of the spur may

have critical roles in fruit development (Barritt et al., 1987; Robinson et al., 1983; Rom and Ferree, 1986).

Summer pruning reportedly increased spur development in the tree canopy interior (Myers and Ferree, 1983). A summer pruning practice commonly used in the Northwest United States includes heading-back cuts on lateral shoots and reducing extension shoots to one after a winter heading cut. Such pruning treatments may influence spur development on the limb sections on which the cuts are made.

A third study was established to evaluate summer pruning on spur development. Thirty 'Oregon Spur Delicious' trees on M.7a rootstocks at the WSU-TFRC Columbia View Orchards (similar to those described above) were summer pruned at: 1) 30 days after full bloom (DAFE), 2) 70 DAFB, or 3) not pruned in the summers of 1982 through 1985. Summer pruning treatments consisted of heading lateral shoots 50%, removing vertical shoots at the main shoot, and reducing multiple shoot terminals to a single shoot. Ten replicated trees of each treatment were used in a completely randomized design. Fifteen vegetative spurs from one scaffold limb on each tree were sampled in Aug. 1985.

Summer pruning at 30 DAFB tended to increase spur leaf number and spur length compared to pruning at 70 DAFB, but neither date was significantly different from the non-pruned control (Table 3). Leaf area per spur and leaf size were both increased ≈10% by the 30-DAFB treatment compared to the control. No interactions between summer pruning treatments and wood age or position within a limb section occurred, and characteristics measured followed the trends discussed above. Pruning tended to accentuate the growth of the most apical spur within a given limb section or the most apical limb section. The greatest differences due to pruning treatments occurred on the 2-year-old limb sections, where pruning 30 DAFB increased leaf area per spur, leaf size, SLW, and bud diameter by an average of 17% compared to controls.

Some of the variation in spur development within a tree appears to depend on factors such as spur age and position of the spur within a limb. The leaf area on the spur late in the season has a quantitative relationship to flower formation but a very limited carryover qualitative relationship to spur and fruit development the following year. Other factors (e.g., environment, crop load, management practices, etc.) during the season of spur development may influence spur and fruit development. For almost all spur characters measured, wood age had a much greater effect than either position or strain. Clearly, young wood and consequently young spurs are potentially more productive than older wood. Spur development can be altered by practices such as summer pruning. An understanding of other factors affecting spur development and that may be incorporated into tree training systems and tree management schemes, likely will be useful to optimize quality fruit production on spur-type trees.

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